A Review of Extended Reality Exercise Games for Elderly

Yu Fu[1][a], Yan Hu[1][b], Veronica Sundstedt[1][c] and Yvonne Forsell[2][d]
[1]*Department of Computer Science, Blekinge Institute of Technology, Karlskrona, Sweden*
[2]*Department of Global Public Health, Karolinska Institutet, Stockholm, Sweden*

Keywords: Virtual Reality, Augmented Reality, Mixed Reality, Extended Reality, Game, Physical Training, Exercise, Elderly, Old People, Health

Abstract: With the increasing of ageing all over the world, elderly health attracts more and more attention. This paper aims to study existing extended reality (XR) game applications for physical exercise through a literature review with 14 papers as an outcome. Based on these papers, we explored the contributions, opportunities, and challenges of exercise XR games for the elderly. The papers were analysed based on several perspectives, including publication information, design and implementation, game information, teamwork and social games, evaluation, and advantages and disadvantages. We found that the elderly were interested in and accepted the use of XR games. The positive effect of such games was common in the research results. Even if there were problems, such as simulator sickness, safety risks, device problems, and cost, there are still opportunities and space for research and development in the future. The overall positive attitudes toward XR exercise games for the elderly could be seen by both researchers, developers, and users. However, these game applications also presented some problems and future improvements are needed. The presented review is beneficial for researchers and developers to create or enhance future XR applications by learning from existing work.

1 INTRODUCTION

The ageing problem is increasing all over the world. From the WHO report on ageing and health (WHO, 2019), people live longer, and the age of the population is increasing. By 2030, one out of every six people in the world will be aged 60 years or over (WHO, 2019)and in 2050, this age group is expected to reach 2.1 billion (WHO, 2019). The ageing problem brings many issues, especially in terms of health challenges, such as joint pain, arthritis, diabetes, depression, and dementia. Moreover, as the age grows, multimorbidity increases. However, there are life style factors that, directly or indirectly, can improve physical and mental health, such as increased regular physical exercise and training (WHO, 2019).

According to the WHO, active ageing ”aims to extend healthy life expectancy and quality of life for all people as they age”. Herewith, one of the key goals is maintaining independence. To achieve this, the level of ADL (activities of daily living) function needs to be sufficient. There is compelling evidence from longitudinal observational studies that sufficient levels of physical activity decrease the risk for declining ADL (Daskalopoulou et al., 2017). Moreover, another term that is often used is frailty, of which there are various definitions, but all of them include a decrease in physical function or independence (Dent et al., 2016; Devereux et al., 2019). There is also evidence that physical exercise in already frail elderly persons has a positive effect (Campbell et al., 2021). Evidence on what type of physical exercise would be most effective is limited. The observational studies include data on various activities such as cycling, dancing, and walking. The intervention studies have used various types of exercise programmes (Lindsay-Smith et al., 2019). However, most physiotherapists are recommending a combination of strength and aerobic exercises.

Exercise at home is often done using, for example a treadmill or bicycle. However, it has also previously been shown that the rate of exercise can decline due to the lack of varied stimuli in the surrounding (Lee et al., 2021a). Digital games have proven beneficial for motivating and engaging by supporting fun and providing a plentiful user experience (Deterd-

[a] https://orcid.org/0000-0003-3520-3302
[b] https://orcid.org/0000-0002-3283-2819
[c] https://orcid.org/0000-0003-3639-9327
[d] https://orcid.org/0000-0002-5118-3148

Fu, Y., Hu, Y., Sundstedt, V. and Forsell, Y.
A Review of Extended Reality Exercise Games for Elderly.
DOI: 10.5220/0010907800003123
In *Proceedings of the 15th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2022) - Volume 5: HEALTHINF*, pages 201-210
ISBN: 978-989-758-552-4; ISSN: 2184-4305

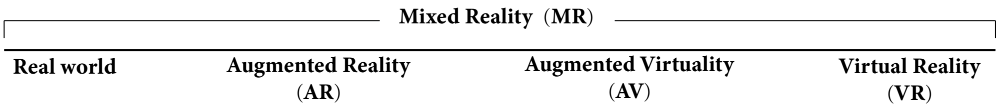

Figure 1: The relationship of AR/VR/AV/MR technique (Milgram and Kishino, 1994).

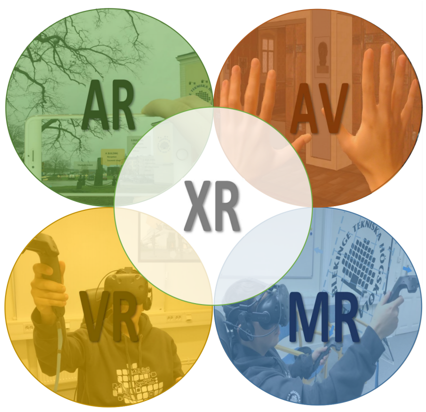

Figure 2: Examples of AR/VR/AV/MR/XR techniques.

ing et al., 2011). Digital games can also support aims and tasks with serious goals, such as exercise and training (Deterding et al., 2011; Sauvé et al., 2017). These games are also referred to as serious games, are not only for fun and entertainment, but also activities such as training, education, or treatment (Djaouti et al., 2015). However, it is because serious games have the attributes of games, they are easier to be accepted and used continuously by users than non-game activities, to achieve serious goals (Wilkinson, 2016). In addition, "gamification" as a concept is usually mentioned in relevant studies and developments summarised from Deterding et al.' gamification research; such term refers to using of design elements characteristic for games in non-game contexts (Deterding et al., 2011).

Adapting Milgram and Kishino's description of the real-world to the virtual world (Milgram and Kishino, 1994), as shown in Figure 1, mixed reality (MR, or hybrid reality) is the merging of the real environment and immersive techniques. According to their description, in a sense, the transition from reality to virtual reality (VR) is the diminishing composition of the real world and progressively increasing virtual objects. In the real world, without digital objects, people interact with the real environment; augmented reality (AR) is to superimpose 3D virtual objects in the real world (Azuma et al., 2001); Moreover, augmented virtuality (AV) creates a virtual world, adds real objects into it (Azuma et al., 2001), instead of operating in the real environment and with digital objects, like in AR. It can be understood as the complement set to AR to a certain extent.

VR simulates a completely virtual world; in other words, in the VR world, all objects are computer-generated (Slater and Sanchez-Vives, 2016). Especially in the use of head-mounted displays (HMDs) VR (one kind of immersive VR), it cuts off the perception of the real world; users could hear, see and interact with objects from the virtual world (Slater and Sanchez-Vives, 2016). In addition, extended reality (XR) is a collection of immersive technologies (including AR/VR/MR), which refers to all real and virtual technologies generated by computers (Çöltekin et al., 2020), as shown in Figure 2.

Furthermore, there has been some evidence that XR games can be good for mental and physical health (Yu Fu, 2021). XR games are popular for their unique immersive experience (PERKINSCOIE and Association, 2021). However, expectations and opportunities of XR technology go beyond digital games. From the 2021 XR industry insider survey by Perkin Coie LLP and XR Association (PERKINSCOIE and Association, 2021), healthcare has once again become the top application field (except for games and entertainment) considered by industry practitioners to be most easily subverted by XR technology. Compared with last year (34% in 2020), healthcare has a higher percentage of approval (38% in 2021). The report also pointed out that due to the impact of the COVID-19 pandemic, people staying at home for several months have strengthened the prospects of XR technology at a certain rate of success, especially in the fields of healthcare and education. Consumers were more comfortable with the experience online and virtual. This means opportunities can be seen of XR techniques combined with games, to provide solutions for elderly physical health.

As a result, this paper aims to review academic research of XR games for elderly physical exercise and training. Based on a literature review of existing XR applications, we analysed such games' characteristics and attributes. We also explored opportunities and challenges, or users' positive and negative attitudes, of such applications. This study pays attention to papers focusing on physical exercise and training, instead of physical exercise with a particular disease as the background motivation. This approach is different from XR game applications that focus on rehabilitation, treatment or prevention of certain diseases (such as stroke rehabilitation, balance training, fall prevention, Alzheimer's disease, and cognition training). To achieve the research aim, our study was conducted with the following two research questions:

- RQ1: What existing research contributions on XR game applications target elderly physical health training?
- RQ2: What opportunities and challenges does elderly see with XR game applications for physical health training?

The rest of the paper is organised as follows. Section 2 describes the retrieval process for the literature review. Section 3 presents the review result into six parts: publication information, design and implementation, game information, teamwork and social games, evaluation, and advantages and disadvantages. Section 4 discusses the results and Section 5 summarises the conclusions and future work.

2 RELATED WORK

Miller et al., targeting older adults (over 45 years), conducted a systematic review (2000 to 2012.07.10) to discover the effectiveness of using VR/gaming systems for physical activity in a home; and the evidence to support the feasibility of using such games for physical activity at home. Based on their review of 14 included papers, they found there was weak evidence with a high risk of bias to prove the feasibility and effectiveness of how VR/gaming could address impairments, as well as activity limitations and participation (Miller et al., 2014). Moreover, they found affect problems of feasibility, such as high dependent training and assistance, acceptability problems, safety problems, high cost, etc (Miller et al., 2014). Furthermore, the report pointed out that the higher function required to use VR gaming activities at home safely; and the higher dependence of training and assistance at the beginning of use (Miller et al., 2014). They also said VR games were good for encouraging motivation; and social engagement (Miller et al., 2014). In addition, they discussed technology costs for both developers and end-users; and that the device development trend will be more sophisticated motion-sensing equipment (Miller et al., 2014).

A review study of VR games for the elderly was also conducted by Campo-Prieto et al. Unlike Miller et al.' work, their research focused on immersive VR (IVR) applied in physical therapy and rehabilitation. In four medical science databases, they retrieved 11 included papers from the 765 publications before 2019.06. Based on those papers, they found few applications of VR games for elderly health. Among these, most studies focused on the acceptability and usage analysis of immersive techniques, such as simulator sickness and VR headsets (Campo-Prieto et al., 2021). Moreover, they saw the use of Simulator Sickness Questionnaire (SSQ), Self-Assessment of Communication (SAC), or System Usability Scale (SUS) to evaluate, and the blood pressure and heart rate monitor for increasing accuracy in the applications' protocols (Campo-Prieto et al., 2021).

They claimed there was no significant difference between VR and immersive VR in the literature, but there was more IVR in physical therapy (Campo-Prieto et al., 2021). HMD Oculus Rift, HMD HTC Vive, and Samsung Gear VR Headset were the most used devices (Campo-Prieto et al., 2021). They also found the combinations of devices with VR for exergames, such as a bike or treadmill, were applied more often (Campo-Prieto et al., 2021). It is worth noting that they thought therapists and developers should work together to match the needs of the target users and improve the attractiveness of user experiences (Campo-Prieto et al., 2021). They also marked and highlighted the challenges, such as device problems and content improvements (Campo-Prieto et al., 2021). They believed immersive VR could help with traditional treatment and rehabilitation by being incentive coupled with fun (Campo-Prieto et al., 2021).

3 SYSTEMATIC LITERATURE REVIEW

To address RQ1 and RQ2, we explored existing contributions from academic studies for XR game applications targeting elderly physical exercise and training, as well as the opportunities and challenges of features or attributes of such applications. Following the four steps in the guidelines of Keele et al. (Keele et al., 2007) as shown in Figure 3, we conducted a systematic literature review using the Scopus database. Based on the keywords (augmented reality, virtual reality, mixed reality, health, game, elderly, exercise, and physical training) and their abbreviations (AR, VR, and MR) or related words (old), we created the search string: ((augmented AND reality) OR (ar) OR (augmented AND virtuality) OR (av) OR (virtual AND reality) OR (vr) OR (mixed AND reality) OR (mr)) AND (health) AND (game) AND ((elderly) OR (old)) AND ((exercise) OR (physical AND training)) for the paper retrieval.

The search results were limited to publication years (2011-01-01 to 2021-08-31), language (English), and paper type (article and conference paper). The title, abstract and keywords review narrowed down the 1585 search results to 99, and further

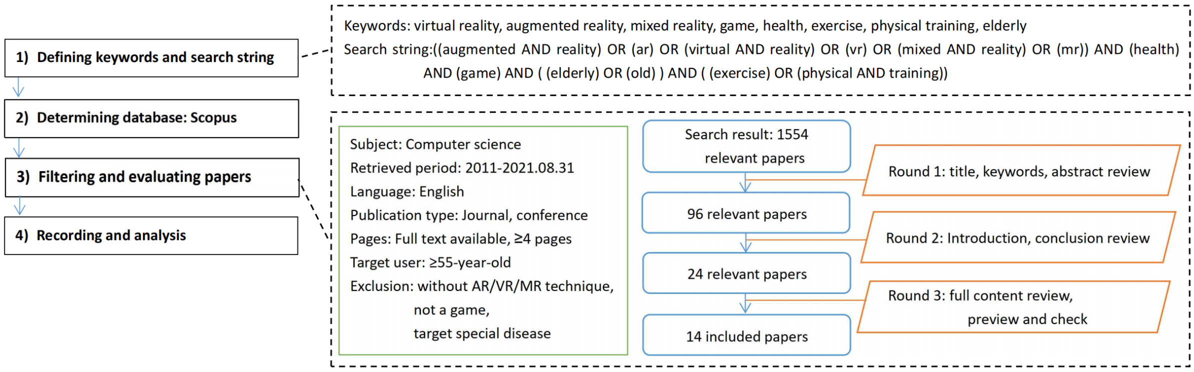

Figure 3: Publication retrieval process.

to 22 by reviewing the introduction and conclusions. Finally, the full content review and preview and check stabilised the included papers at 14, which were analysed further. As previously mentioned, we only included research targeting ”pure” exercise and physical training for the elderly, and excluded papers that were relevant to treatment/prevention/rehabilitation of specific diseases and health issues, such as stroke, fall, dementia, Parkinson, cognitive training, memory training, and Alzheimer's disease. Based on the convention from the UN, the referring of the elderly people was age over 60-year-old (Kowal and Dowd, 2001). However, in some other research, the age could be narrowed to 55-year-old (Ferreira and Kowal, 2006). Thus, to cover more research, as a baseline for the elderly, we aimed at an age in the included review papers being 55-year-old or more. Some papers resulting from the search were also excluded if the studies did not mention XR (6), being without game elements (1), having less than four pages (1), or if the full content was not available (6).

4 RESULTS

Based on the 14 included papers, we analyse the reviewed research that has been conducted to answer RQ1 and RQ2. There were four papers (Arlati et al., 2019; Pedroli et al., 2018), (Grani and Bruun-Pedersen, 2017; Bruun-Pedersen et al., 2016) which came from two projects with different research content. Thus, we analysed them as four individual studies. To discover the contributions of the academic studies of XR game applications for elderly exercise and physical training and opportunities and challenges for such game applications, we analysed the included papers in five areas as previously mentioned. These were: 1) publication information, 2) design and implementation, 3) game information, 4) teamwork and social games and 5) evaluation.

4.1 Publication Information

All included papers came from 2016 to 2021; it is worth noting that no included studies were published between 2011 and 2015. The included research in 2021 was the highest and reached four papers; the following were three in 2020; two in each of the years (2016, 2019, 2018); and only one from 2017. The authors of these 14 papers involved 12 countries and regions. More than 60% (9/14) of the included papers are research institutions from Europe and the United States (Spain, Norway, Australia, Denmark, US., Italy, Netherlands), followed by Asian countries and regions (South Korea, Japan, China, Hong Kong China).

4.2 Design and Implementation

Almost all 14 included papers were conducted by academic researchers; they usually came from different departments, such as medical subjects (neurology, psychology, geriatrics, etc.), computer and engineering subjects (electronic information, industrial technology and automation, etc.), and media and communication subjects. Two papers included authors from the hospital or nursing home, and one study mentioned software developers in their research.

As shown in Table 1, games with VR technology (including immersive and non-immersive VR) accounted for more than 70% (10/14) of the included articles. Among them, three used a large screen and other equipment to create a non-immersive VR environment, one paper used a CAVE, while the other six applications used HMDs to achieve an immersive VR experience. Three papers mentioned they used the AR technique based on Kinect, the same as the papers in the non-immersive VR technique. Only one study used MR technology with the HoloLens. It is worth noting that in the same application, the authors changed and updated their display device from

Table 1: The analysis of the included papers based on technology, game, and evaluation viewpoints.

Technology				Game				Evaluation					
Technique		Display	Controller/tracker	User type	Posture	Genre	Task	Number	Age	Method	Index	Scale	Refer.
VR	Immersive	HMD	limb motion trackers	single	sitting	simulation	handball, football, gatekeeping	135	62.7	E,Q	usefulness, user experience	null	(Chau et al., 2021)
			hand controller, ankle controller	single	stand	action game	change action by different shape and color, feed animals	20	≥ 65	E,Q	usefulness, user experience	Player Experience (PX)	(Li et al., 2020)
			null	single	sitting	simulation	cycling	20	63.6	E,Q	usefulness, user experience	stress arousal checklist(SAC), simulator sickness questionnaire (SSQ), ITC sense of presence inventory (ITC-SOPI), Borg rate of perceived exertion scale(RPE)	(Sakhare et al., 2019)
			Speed sensor	single	sitting	simulation	cycling	null					(Ijaz et al., 2016)
		HMD/TV	WiFi microcontroller (on pedal)	single	sitting	simulation	cycling	null					(Grani and Bruun-Pedersen, 2017)
		CAVE	cycle-ergometer, Arduino, motion tracking system hardware interface	single	sitting	simulation	cycling	5	≥ 59	E,Q	usability	system usability scale (SUS)	(Pedroli et al., 2018)
	Non-immersive	TV (curved screen)	Arduino, hardware interface, Hall effect sensor (on chassis), Inertial sensor (on headset)	single	sitting	simulation	cycling	5	≥ 65	E,Q	usability, acceptability	SUS, SSQ	(Lee et al., 2021b)
		big screen	cycle-ergometer, Arduino, hardware interface	single/ multiple	sitting	simulation	cycling	null					(Arlati et al., 2019)
		TV	Arduino	single	sitting	simulation	cycling	24	null	E,Q	user experience	Intrinsic Motivation Inventory (IMI)	(Bruun-Pedersen et al., 2016)
		null	Kinect	single/ multiple	stand	simulation	bowling	19	68	E,Q	usefulness, user experience	With the Physical Exercise Adherence Questionnaire, Game Experience Questionnaire (GEQ)	(Júnior et al., 2021)
AR		null	Kinect	single	stand	simulation	put bird to cage	57	≥ 65	E,Q	usefulness, usability, acceptability	SUS, Usefulness Satisfaction, Ease of Use, Happiness, Importance,	(Muñoz et al., 2021)
		screen	Kinect	multiple/single	stand	action game	imitate actions	27	≥ 65	E,Q	usefulness, user experience	Exercise Self-Efficacy Scale (ESE)	(Jeon and Kim, 2020)
			Kinect	single	stand	adventure	island adventure	3	43-62	E,I	usability, user experience	null	(Nishchyk et al., 2020)
MR		HoloLens		multiple	stand	shooter	shooting rabbit	null	null	E,I	user experience	Game experience questionnaire (GEQ)	(Buckers et al., 2018)

Note: 1) In the "Method" column, "E" represents the experiment, "Q" is the questionnaire, and "I" denotes the interview. 2) In the "Age" column, the unit is the year; numbers without signs and intervals represent the average. 3) In the Table, "null" means did not mention such information in the papers.

a CAVE (Pedroli et al., 2018) to a large screen (Arlati et al., 2019).

Most of the included papers had indoor bike applications, that allowed users to interact with a stationary bike system. They normally had sensors on them, such as speed sensor (Ijaz et al., 2016), hall effect sensor, and inertial sensor (Lee et al., 2021b). Except for sensors, such games usually use the hardware interface on the handlebar for control and interaction (Pedroli et al., 2018; Lee et al., 2021b). It is worth noting that two bicycle-related articles mentioned heart rate detection. Research in (Sakhare et al., 2019) used the Borg RPE scale and heart rate to calculate the exercise intensity, while in (Arlati et al., 2019), the heart rate was used to adjust the bicycle ergometer to maintain a constant level of effort.

AR games mainly used the Kinect as the motion sensor and interactive way to capture the users' actual movements and control system. Only one paper (Li et al., 2020) used two hands and two wearable controllers to detect hand and ankle movements. The MR study used gesture control with the HoloLens. Moreover, nine papers mentioned development and operation software, all of them were done in Unity.

4.3 Game Information

Game genres and tasks in the 14 included papers were overlapping to some extent. We could see seven of them using an indoor bike as part of their game task. Except for cycling in a simulation environment, some studies combined other tasks to train cognition simultaneously. For example, in the indoor game from Arlati et al., they asked the user to find all animals along the way that start with a particular letter (Arlati et al., 2019) and guess the city name based on the landmark. The animal was also used in work by Munoz et al. (Muñoz et al., 2021) as the game object. Their application supports shoulder training by asking users to raise their arms to put a bird into a cage. Chau et al. studied a set of VR games facing a different group of users (Chau et al., 2021). They covered physical training with ball games, such as handball for upper limbs and football for lower limbs. In addition, Junior et al. used a bowling game as part of their game task (Júnior et al., 2021).

Game genres were not only the above three kinds of simulation games, but also action, adventure, and shooter games. Li et al. provided a VR game to impact the elderly's cognitive and physical health (Li et al., 2020). They asked users to change their posture and location by following different shapes and colours of objects and feeding animals. Jeon and Kim also designed an action game for elderly exercise; the game task was following the non-player character's actions, thereby achieving the aim of physical training (Jeon and Kim, 2020). Furthermore, an adventure game was also in the included papers. Nishchyk et al. created an AR game based on a story on an island with a pirate, their parrot, and treasure chests (Nishchyk et al., 2020). Game tasks embodied physical exercise and revolved around treasure hunting, including climbing stairs and "flying" by controlling the parrot. Moreover, users of the VR game by Buckers et al. were tasked with shooting rabbits (Buckers et al., 2018) to exercise the whole body.

From the view of using posture, except for the seven bike applications that asked users to sit on an indoor bike, almost all other seven studies used a standing posture. Even someone who only focuses on upper limbs' training was also using a standing posture (Muñoz et al., 2021). The game elements, such as rewards, avatars, and points, were used in the included papers. Among those elements, the points were the most used.

4.4 Teamwork and Social Games

The work presented by Júnior et al. not only contributed an application but also compared the difference of fitness test, physical exercise adherence, and game experience between a team member user or a single user before and after use (Júnior et al., 2021). They pointed out that although the single playing results of the physical fitness test had improved, the increase had significantly improved in the team playing scenario. Moreover, the score of sensory and imaginative immersion in the team was higher. Furthermore, a teammate can provide support when players feel sad, pain, or difficulties, to help them continue playing. Moreover, Arlati et al. provided a social VR bike game (Arlati et al., 2019). They implemented the VR training with other players. Through multiplayer mode, users were allowed to have voice contacts with others, training collaboratively or competitively. It can not only help with physical health but also reduce the risk of social isolation. Furthermore, Buckers et al. created a virtual dodgeball game (Buckers et al., 2018). Two users were playing together to shoot balls in the direction of a rabbit target. They believed those games were more attractive and engaging.

It is worth noticing, multiple-user games typically run online, but single-user games are not. They usually use offline mode. However, there were exceptions. The one was a single-user game, which could connect with the web client (Muñoz et al., 2021). And the other one was a multiple-user game, which could identify two users in offline mode. Thus, the website is not necessary (Jeon and Kim, 2020).

4.5 Evaluation

From an evaluation point of view, except for the three included papers, which did not mention assessment as part of their applications, we found similar methods and tools in different studies. The main evaluation method was combining an experiment and questionnaire to learn the effectiveness and usefulness by comparing the health situation before and after use and obtaining the satisfaction level in subjective user feedback at the end of the experiment. Standardized scales were the most common tool for the questionnaire method in the included papers, as shown in Table 1. Usability, simulator sickness, game/player experience received the most attention of the included papers. The number of participants ranged from 3 to 135 in the included studies. Typically, the interviewees were classified as experiment and control groups randomly. However, some studies also tried to compare the differences between age groups to divide the respondents by age (elderly vs younger).

4.6 Advantages and Disadvantages

Based on the evaluation result from the included papers, we could see an overall positive attitude of XR game applications for physical health and exercise training from the elderly, but still some problems to address in the future. Some previous studies pointed out that older people have a negative tendency towards new technologies (Hauk et al., 2018; Lee et al., 2003). However, the evaluation results from the included papers were all positive. Sakhare et al. claimed that age did not significantly affect the feasibility of VR for the elderly (Sakhare et al., 2019). Even the most outstanding progress during the experiment was the group of the oldest people (75–80) (Muñoz et al., 2021). Positive comments also covered high levels of learnability, ease and confidence in use and acceptability (Lee et al., 2021b). Others were being innovative, fun, interactive, and exciting (Chau et al., 2021), interesting and engaging (Nishchyk et al., 2020) or benefiting physical and mental health (Muñoz et al., 2021; Júnior et al., 2021; Li et al., 2020; Jeon and Kim, 2020).

Challenges could be classified as simulator sickness, device problems, and improved content. Three papers used the simulator sickness questionnaire. They have similar results, that there were symptoms such as dizziness, nausea, and disorientation during use, but they were all mild and acceptable (Lee et al., 2021b; Chau et al., 2021; Sakhare et al., 2019). Sakhare et al. believed the significant effect factor of sickness was time, not age. The research by Chau et al. can also support this view. They found that over half of the uncomfortable reports came from the first four times of use (Chau et al., 2021). There was a paper that not only pointed out the simulator sickness problem but also provided some solutions, such as limiting the viewing range and reducing the content, using more realistic VR photography technology, stabilizing the viewpoint, using active VR experiences instead of passive, and based on curved TV instead of HMD (Lee et al., 2021b).

Device problems were mainly focused on the low user experience of HMD and controller/sensor. Chau et al. said they would enhance the HMD to be more portable and adjust the sensor to be unnecessary to upright operation (Chau et al., 2021). The negative user feedback of VR headset was received from Lee et al.' research and Li et al.' study. The weight of the HMD might lead the disorientation caused by head pressure (Lee et al., 2021b). The VR HMD was a bit heavy, and with improper wearing, mistakes could easily be made (Li et al., 2020).

The content enhancements were not common comments and were usually specific to the application. The application by Chau et al. was advised to improve the scoring system to enhance the sense of accomplishment and add personalized scoring (Chau et al., 2021). There was a similar improvement requirement in rewards for the application design by Arlati et al.. It was asked to increase the value rewards to enhance motivation and enjoyment (Arlati et al., 2019). Their research also found that game content full of memories for users was more popular (Chau et al., 2021). Furthermore, Júnior et al. thought avatars in games are a stimulus to increase participation (Júnior et al., 2021). Moreover, the feedback needed to be added when the player made mistakes; and the skip function for jumping the background story video was the suggestion for the work by Nishchyk et al. (Nishchyk et al., 2020). Comments from the study of Pedroli et al. were focused on virtual environment and interaction, such as enhancing realism and improving proactive interaction, increasing objects' identify, and reducing interference (Pedroli et al., 2018). In addition, improving the sense of reality was also repeatedly raised by respondents (Bruun-Pedersen et al., 2016).

5 DISCUSSION

Based on the results, with the similar consequence of related studies (Yu Fu, 2021; Fu et al., 2021), although not rich, we could see increased attention of XR game applications to the physical health of the elderly. Although papers before 2016 were not included, the rise in academic research was obvious in the following years. Significantly, the included articles in the first three quarters of 2021 had exceeded the previous full year and doubled than 2019 and 2018. Moreover, judging from the data in this review, the number of researches on such applications in Europe and the United States has obvious advantages. Especially Italy and Denmark have more than two included papers. Furthermore, since such applications are interdisciplinary, the academic background of the researchers was mainly computer and engineering, but it tended to be diversified.

Immersive techniques did not have equal attention. Augmented virtuality exercise game for the elderly was not included in this review. There was only one paper in the search result, which used the AV technique for the elderly but was excluded due to the target health problem belonging to mental health. In addition, the VR technique was much more focused than AR/MR. Especially the immersive VR (with HMDs) contributed to the most previous solutions for elderly physical exercise, including the most used application: indoor cycling, and other types of games with more room for development, such as bowling, ball games, and action games. Although immersive VR was the mainstream, HMD was the main display device in this review. There were still three included papers using the large screen as the display in non-immersive VR, consideration of safety, experience, and cost. The replacement of the CAVE mentioned in the results is also out of this consideration.

Addressing the attributes and characteristics of the elderly, the existing research showed the considerations in the use of posture, motivation to use, and interaction methods as well. It can be seen that the included papers prefer to use a sitting posture rather than standing. Similar to the related work (Miller et al., 2014; Campo-Prieto et al., 2021), gamification technique and game elements were applied to increase the fun and interest, thereby motivating users to continue using the applications to achieve the exercise aim. The interaction and control should be simple and directed to the elderly. So the less equipment, the easier interface, the better experience could be a developing trend. Although we were targeting specifically the elderly' physical health, it is undeniable that physical and mental health affect each other. A study by Sauvé et al. also suggest the effect of digital games, for the elderly, to include three dimensions of quality of life: psychological, physical, and social (Sauvé et al., 2017). The existing research mentioned this from two views: double tasks and social games. Some design their exercise games with mental training tasks (Arlati et al., 2019; Pedroli et al., 2018) or with benefits for cognition and attention (Li et al., 2020). Others added features for multi-user mode to allow teamwork and social interaction in their games (Júnior et al., 2021; Arlati et al., 2019), which was beneficial for the mental health of users.

For the opportunities of XR game applications for the elderly physical health, we could see evidence of acceptance of those techniques by the elderly. They have positive attitudes towards such techniques applied for their physical health improvements. The effectiveness of those VR exercise games was proven acceptable as well. What needs attention in the study and development of such games is the more straightforward operation in design, clear training of use for users, fixing the challenges of simulator sickness and content, as well as device improvements. As the results of an earlier survey (Fu et al., 2021), the first three obstacles to mass adoption are user experience, content offering, and cost to consumers.

Some included papers evaluate the simulator sickness of their games. They claimed the test results were acceptable (Chau et al., 2021). However, this is based on the anticipation and avoidance of uncomfortable situations in the design and implementation stages. For example, Lee et al. propose to stabilize the viewpoint, reduce the viewing range, etc., to reduce VR dizziness (Lee et al., 2021b). Moreover, there was evidence that with an increased use time, the uncomfortable symptoms were reduced (Sakhare et al., 2019). The comments for content improvement were the most specific and detailed, such as adding a skip function for jumping the background video, more motivating elements (score, rewards, unlockable levels, etc.), and error operation feedback to user (Nishchyk et al., 2020). Except for the suggestions about rewards, avatars, in-time feedback, and the shared memory content being the more popular; we need to see the importance of user participation in the design and evaluation. The experience of VR games is more dependent on the device than AR. The uncomfortable weight and cables and low experience of HMDs were also mentioned in previous surveys (Fu et al., 2021; Yu Fu, 2021).

6 CONCLUSIONS AND FUTURE WORK

Aiming in discovering the existing research contributions on XR game applications that target elderly physical health training, and its opportunities and challenges in study and development, this study conducted a systematic literature review using the Scopus database. From the 1585 search results, we included 14 papers for a deeper analysis. Based on the included papers, we summarised and analysed their publication information, design and implementation, game information, teamwork and social games, evaluation, and advantages and disadvantages. Through the above results, we found that the interests and acceptance of the elderly in XR games and the positive health effects of continuous use are opportunities and space for developing such software further. Moreover, the reduction of discomfort and safety risks in use, the improvement of hardware technology, and the improvement of content are the main challenges that research and development need to face in the future. This paper is helpful for researchers and developers working in the area, which give full play to advantages and reduce negative impacts of the XR technique and game technology, in their studies and projects of elderly physical health. Future work could extend the search to more databases and narrow down the application content and technical scope to find more detailed references.

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